EFFECTS OF GEOLOGICAL FAULTS ON LEVEE FAILURES IN SOUTH LOUISIANA

Prepared for Presentation and Discussion

U.S. Senate Committee
on Environment & Public Works

Senator James M. Inhofe, *Chairman*
Senator James M. Jeffords, *Ranking Member*

Present by

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November 17, 2005
Washington, D.C.

EFFECTS OF GEOLOGICAL FAULTS ON LEVEE FAILURES IN SOUTH LOUISIANA

Testimony of

Sherwood M. Gagliano, Ph.D.[1]

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Introduction

Hurricane Katrina slammed into the northern Gulf of Mexico coast on August 29, 2005, exposing numerous low and weak spots in the levee system surrounding New Orleans and other communities of southeastern Louisiana. In some areas the levees were overtopped by elevated water and/or wind-driven surge, but in other places breaches occurred along navigation and drainage canals causing devastation to densely populated inner-city neighborhoods in the Greater New Orleans (GNO) area. Some, if not most, of the breaches that occurred are in places where the levees were built across geological faults. This statement focuses on these failures where there is an apparent relationship to faulting, a largely overlooked natural hazard. Figure 1 shows the spatial relationship between existing and proposed levee alignments and major geological faults in southeastern Louisiana. Shown in Figure 2 are the locations of the Hurricane Katrina levee and floodwall breaches in the GNO area.

The findings and interpretations presented in this statement are the result of a five-year research effort regarding fault movement and resulting landform change in south Louisiana and southeast Texas. Some results of the work have been published in

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scientific journals, engineering journals and technical reports and have been presented at numerous meetings of professional associations and public bodies. Field inspections have been conducted at most of the breach sites in the GNO area, but little detailed site specific study has been conducted by the author at this time. For additional information see: Publications at [www.coastalenv.com.](http://www.coastalenv.com)

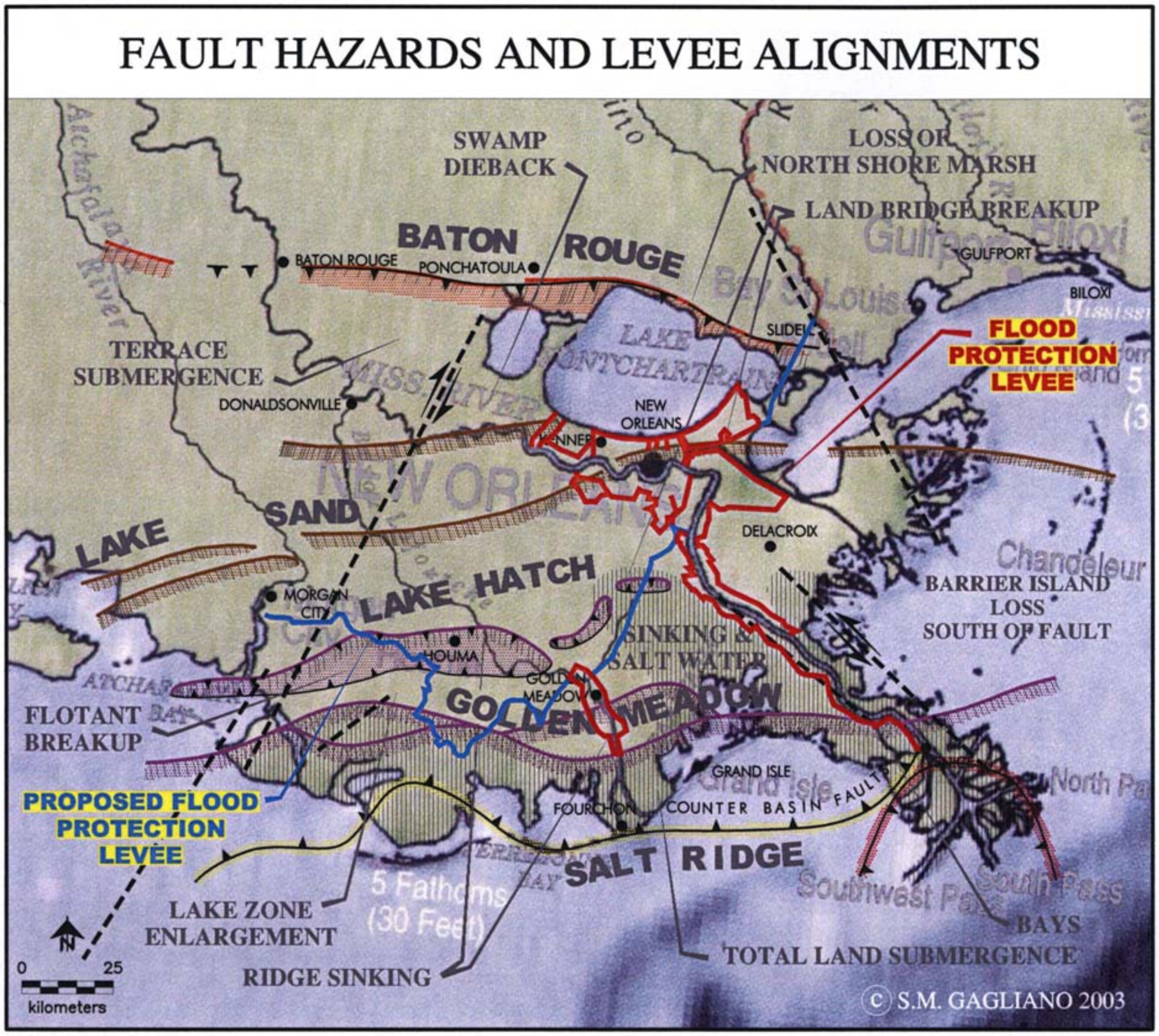

Figure 1. Existing and proposed hurricane protection levee alignments in reference to major geological faults in southeastern Louisiana.

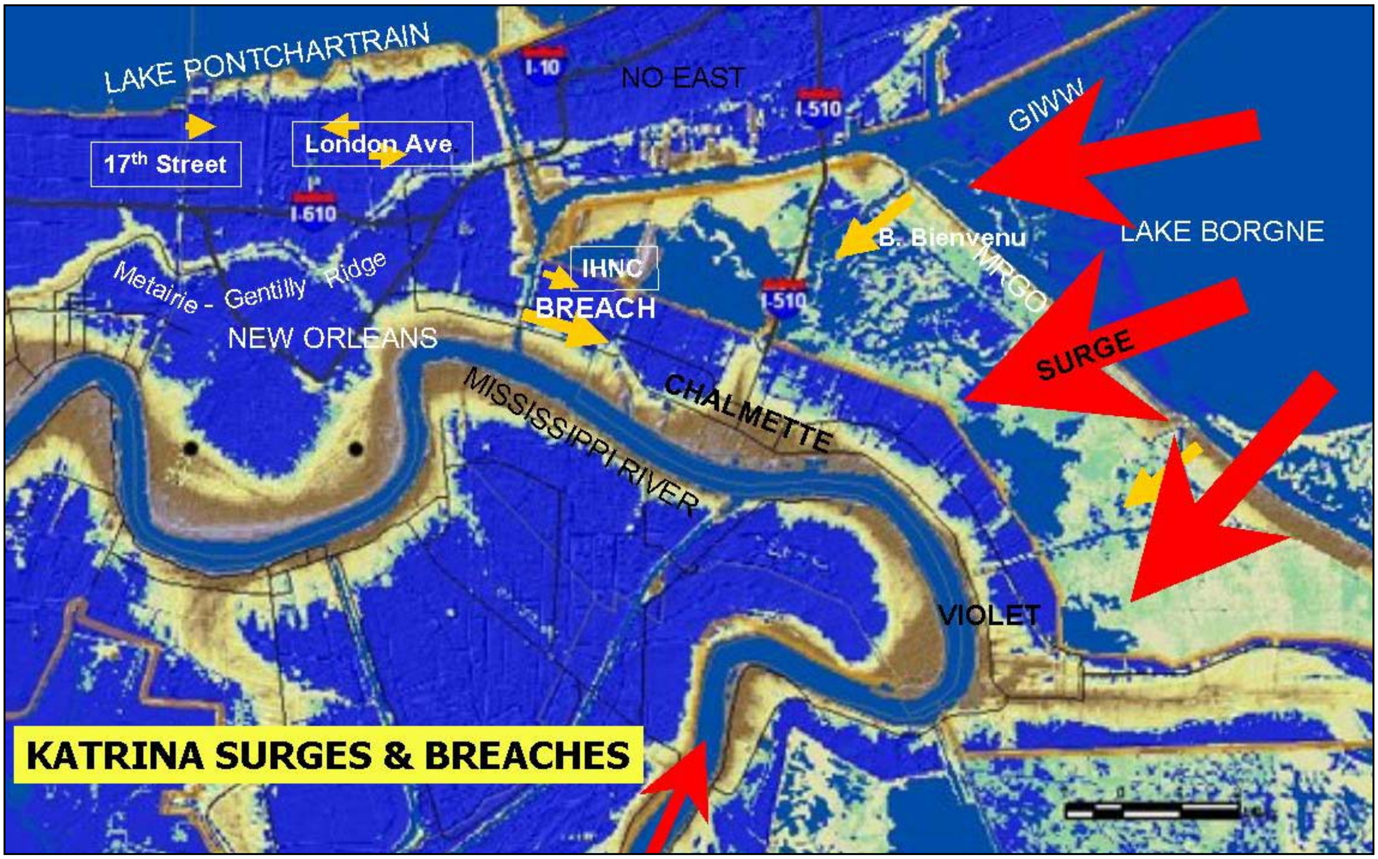

Figure 2. Location of levee and floodwall breaches that occurred during Hurricane Katrina in the Greater New Orleans area. Backdrop is a satellite image showing extent of flooding.

Faults and the Tectonic Framework

South Louisiana is underlain by a maze of faults, which are known primarily from information gathered during exploration for oil and gas. These east-west trending features are classified as growth faults because many of the sedimentary beds that are cut by the faults are thicker on the down-thrown block, indicating that the faults moved during deposition. The faults are components of a regional linked tectonic framework that has been in motion for more than 100 million years and is still moving. Many subsurface faults within this system have been correlated with surface faults (Figure 3). The most common type is the growth fault, characteristics of which are shown in Figure 4. Surface effects of growth fault movement on landforms and near-surface deposits are shown diagrammatically in Figure 5. Fault movement affects surface landforms and

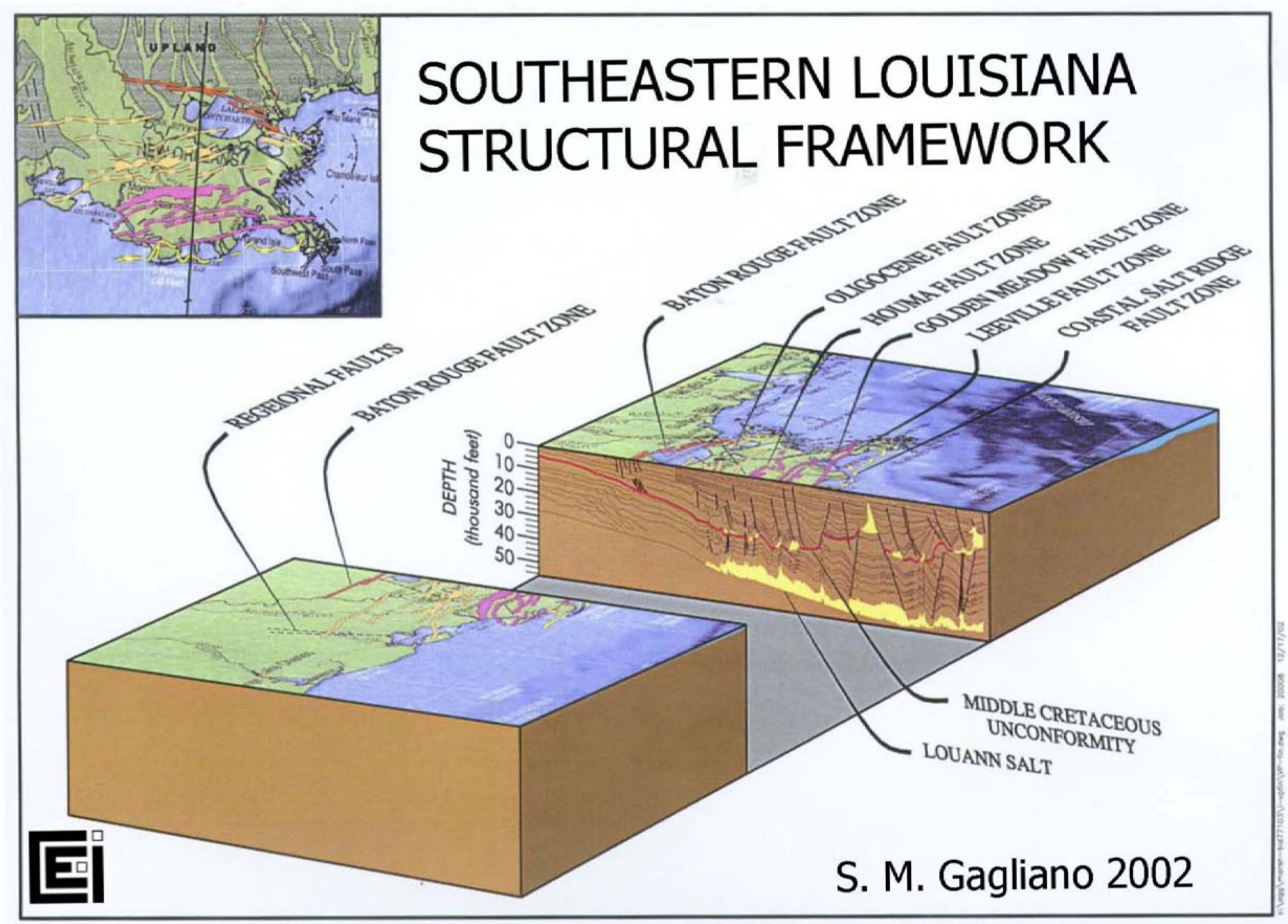

Figure 3. Active surface faults have been correlated with ancient deep-seated faults. Southeastern Louisiana overlies a deep, sediment filled structural trough, the bottom of which is 35,000 to 50,000 feet below the surface. The bases of active faults in the GNO area are 25,000 to 30,000 feet below the surface.

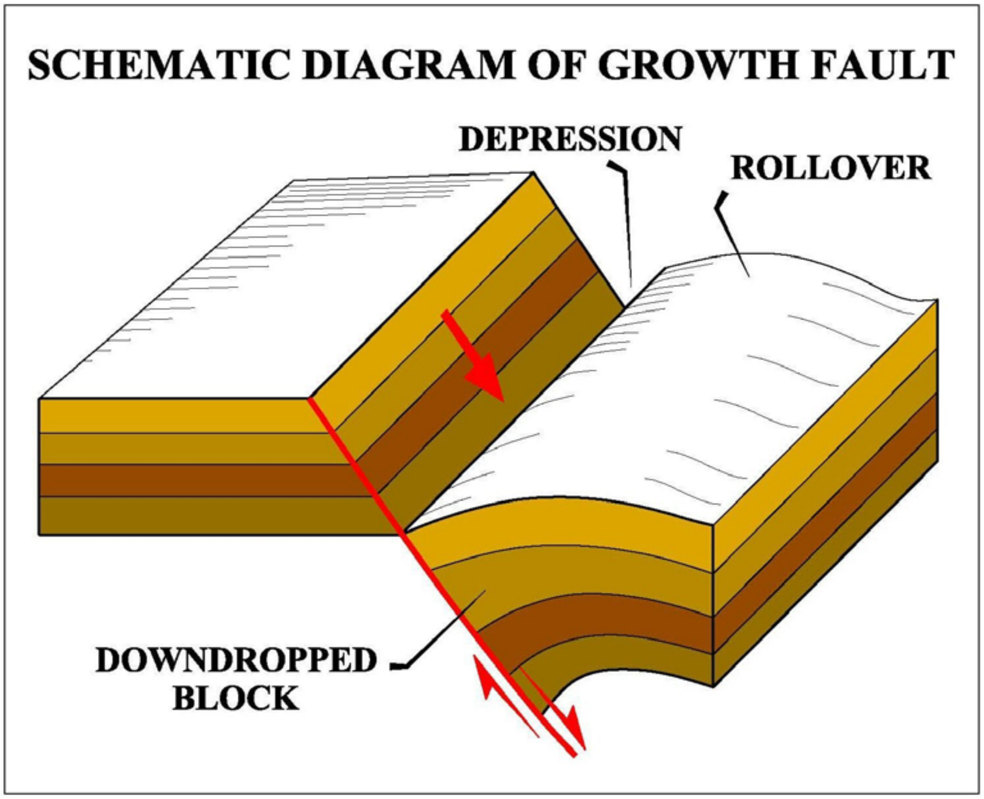

Figure 4. **Growth faults are breaks in beds of rock or sediment where slippage has occurred. Individual beds are characteristically thicker on the downdropped block indicating movement of the fault during deposition of the beds. As the downdropped block slides along the fault plane, it tends to rotate, resulting in a depression aligned along the fault trace and an uplift or rollover structure forms in a down dip direction. Movement along the faults may be at intermittent intervals and, or slow and imperceptible, but the movement continues over long periods of time.**

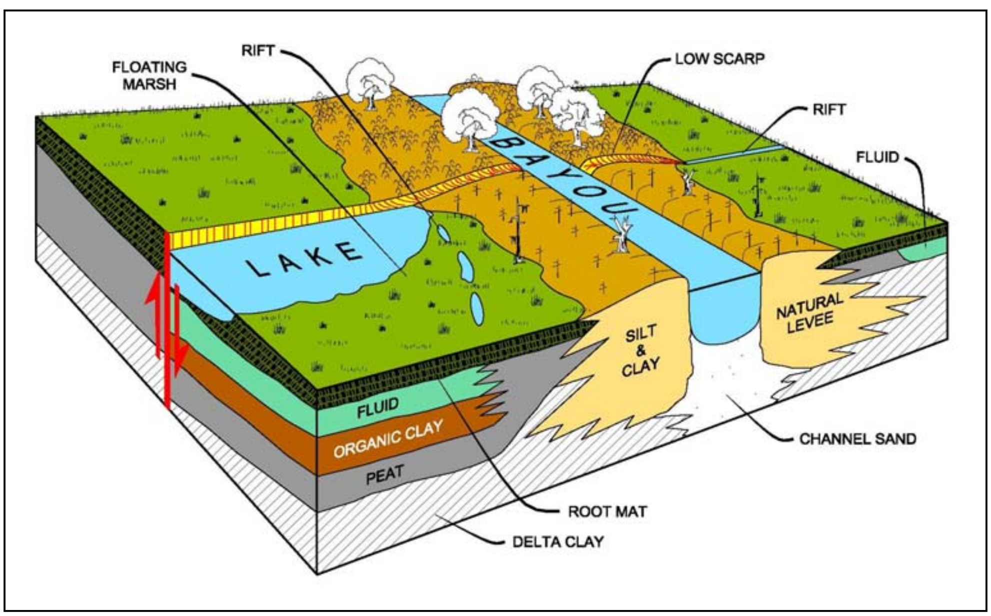

Figure 5. **Diagram showing effects of growth fault movement on different landforms and near-surface deposits in the deltaic plain of southeastern Louisiana. The effects on flood protection levees and floodwalls are similar to those on the natural levee ridges bounding the bayou.**

infrastructure including ridges, barrier islands, wetlands, flood protection levees, highways, and coastal communities. Barrier island breakup, the massive land loss that has occurred in the area during modern decades, as well as many river bank failures are all linked to fault movement. A cause and effect relationship has been established between modern fault movement and the catastrophic land submergence and loss that occurred in coastal Louisiana during the past century (Gagliano et al. 2003a, b.) Depressions along faults and fractures, and tilting of fault-bound blocks also strongly influence the alignment and channel-meander geometry of the Mississippi River and its distributaries in the deltaic plain.

The GNO area lies along the upper margin of the Eastern Province of the Gulf Coast Salt Dome Basin (Figure 6). Movement is occurring on deep-seated faults that are part of the tectonic framework. The Eastern Province is in effect a giant gravity slump block, the toe of which lies in the deep waters of the Gulf of Mexico (Figures 6 and 7). The tectonic framework is the response to this massive continental margin slumping, which is driven primarily by basin sinking, sediment loading, gravity, and movement of underlying salt deposits. Onshore components of the linked framework are expanding or pulling apart and thus creating surface depressions and block tilting, while offshore components are contracting into folds and thrust faults that are piling up at the base of the continental slope. Crown faults at the head of the Eastern Province slump underlie the GNO and may be the cause of the floodwall breaches. Secondary processes, which may result in localized subsidence, include sediment compaction, soil de-watering and fluid withdrawal (ground water, hydrocarbons and produced water).

Figure 8 shows known major subsurface faults, geofractures, salt domes and depth to the weathered surface that marks the top of the Pleistocene deposits. The depth to the Pleistocene deposits is important from the geotechnical standpoint as this is a load-bearing horizon and above it lies poorly consolidated Holocene deposits. Depth to the top of the Pleistocene is less than 100 feet throughout the GNO region.

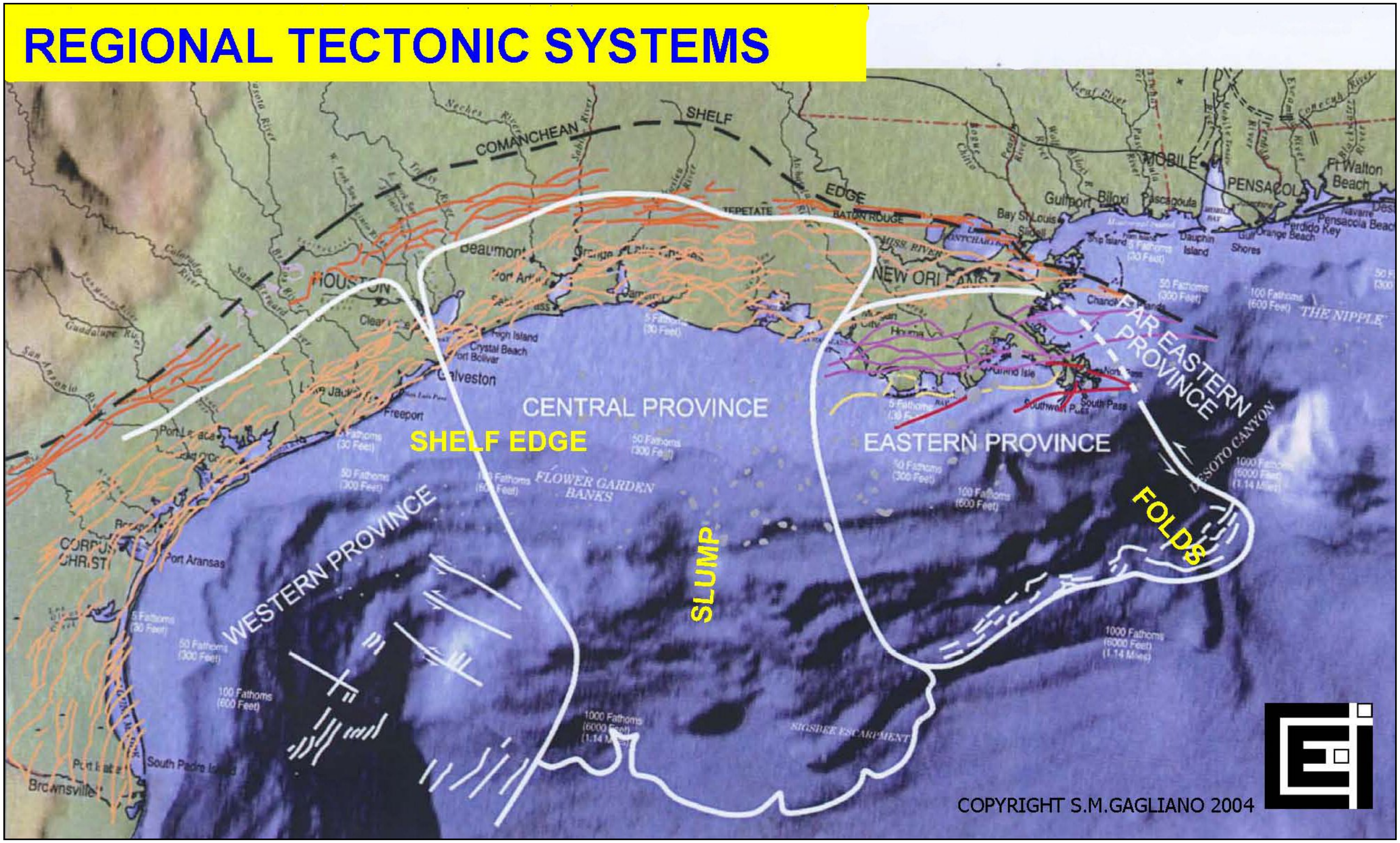

Figure 6. The onshore faults and fractures are parts of linked regional tectonic systems that extend into the deep Gulf. The crown faults of the Eastern Province underlie the Greater New Orleans region (base map with permission of Port Publishing Co., Houston Texas, structural provinces after F. J. Peele et al. 1995, faults after GCAGS).

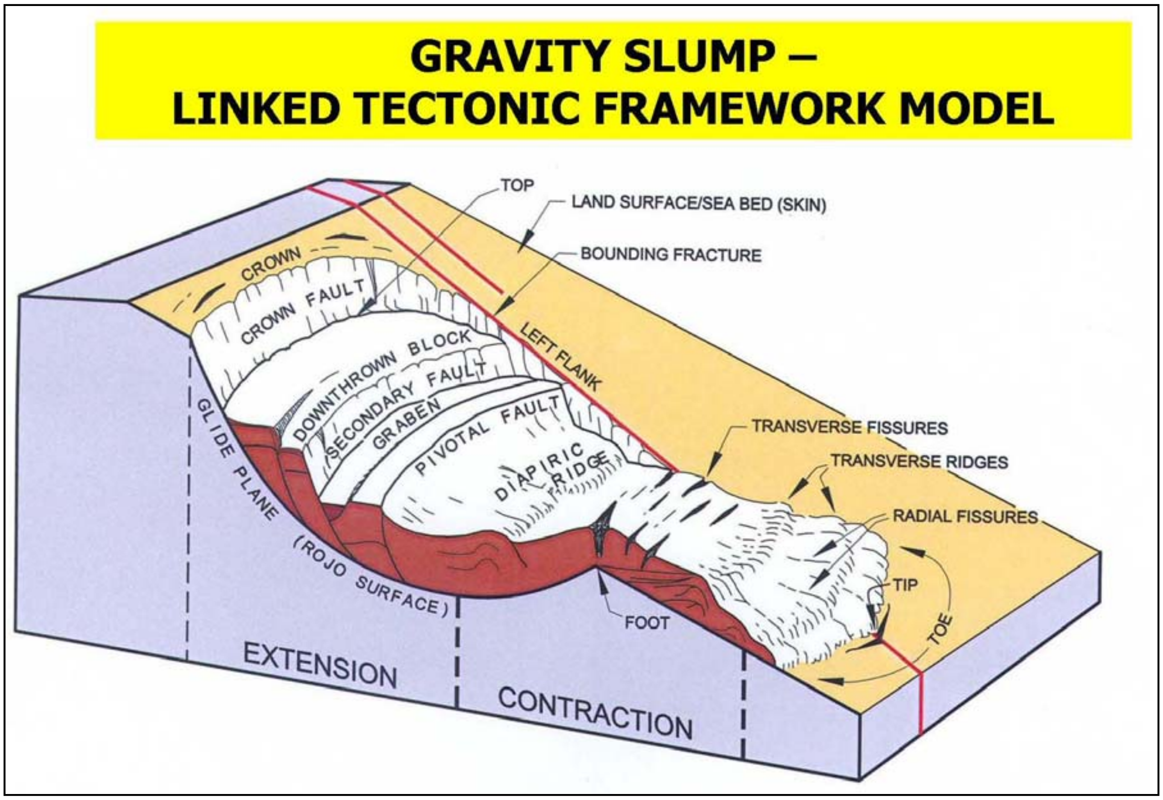

Figure 7. Gravity slump model showing relationships of structural elements of the Eastern Tectonic Province, as shown in Figure 6.

The Baton Rouge Fault Zone, a major regional feature associated with the Comanchean Shelf Edge, marks the eastern boundary of the Gulf Coast Salt Dome Basin. Surface escarpments along this fault zone separate Lakes Maurepas and Pontchartrain and their surrounding wetlands from the pine-covered terracelands of the “North Shore.” Segments of this fault zone along the north shore of Lake Pontchartrain are known to be active during modern times. Highway pavement cracks and railroad tracks require frequent adjustment where they cross the fault zone.

A series of Oligocene growth faults underlie Lake Pontchartrain and the GNO region. These faults are related to the crown faults of the Eastern Province and include the Frenier and Lake Sand-Thibodaux Faults. Displacement of the top of the Pleistocene has been documented on segments of these faults. In addition, highway and railroad bridges

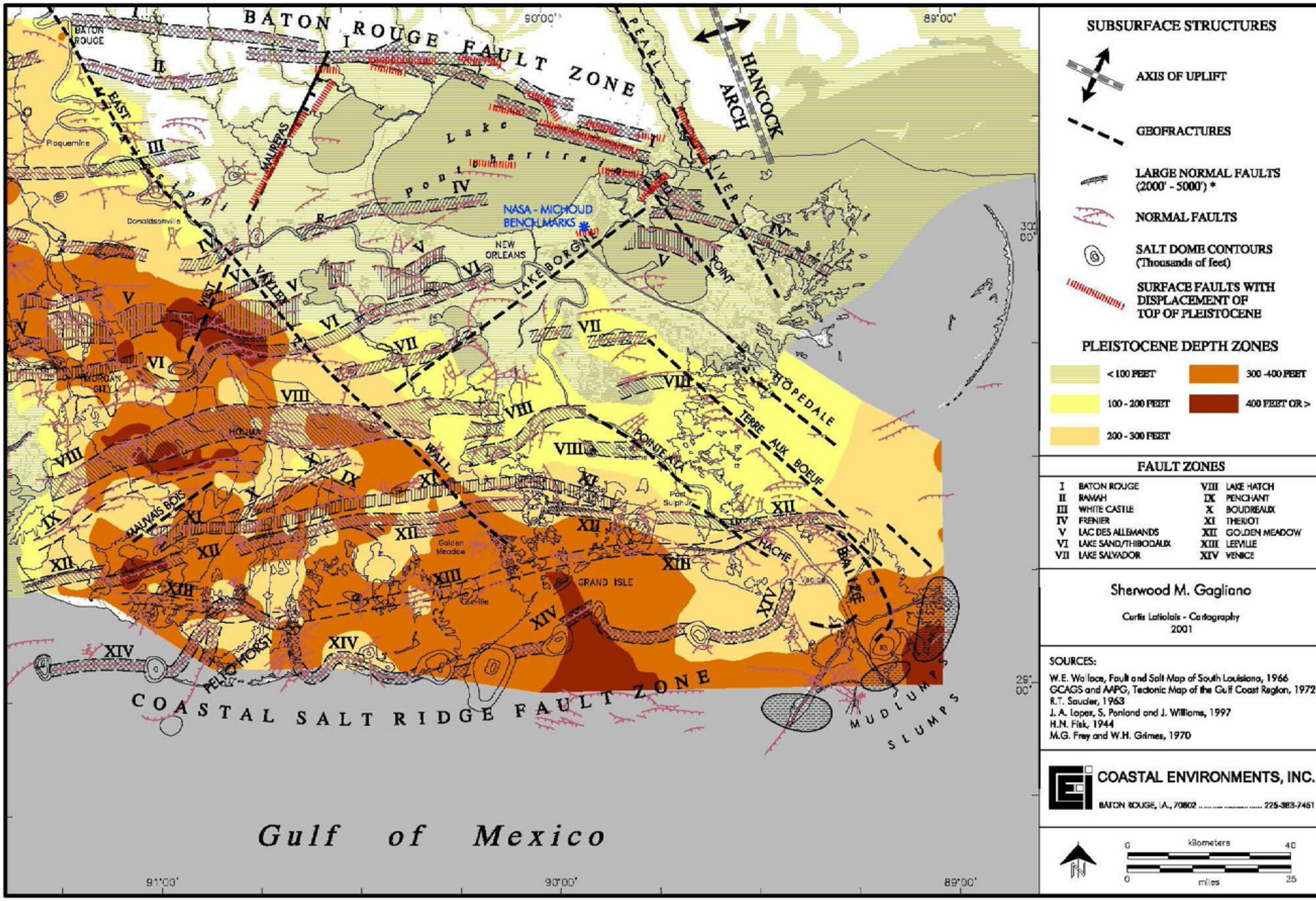

Figure 8. Map showing depth to the weathered surface of the Pleistocene, geofractures, subsurface faults, and salt domes (modified from Gagliano et al. 2003a, Pleistocene depth data from L.D. Britsch per. comm. 2001).

across Lake Pontchartrain are cracked, offset and displaced where they cross the faults. These displacements have been well documented in the geological literature (Lopez et el. 1997). It should be noted that salt domes are absent or rare in the GNO region.

Geofractures constitute another important category of structural features. An extension of the northwest - southeastern trending Terre aux Boeufs Geofracture cuts through the area. This feature segments the blocks between some of the regional growth faults and other faults terminate at their intersection with the geofracture. The Lake Borgne Geofracture (Fault) Zone strikes northeast - southwest and has played an important role in determining river geometry as well as the formation of lakes and bays. Fault segments in this zone may have played a role in the floodwall breach along the Inner Harbor.

Although some regional faults have been active for millions of years, contrary to common belief, not all movement has occurred during the dim geological past. Some faults have moved during the Pleistocene Epoch, prehistoric Native American times, historic times and modern decades. Surface effects of fault movement have been reported from numerous locales across south Louisiana (Lopez et al. 1997, Gagliano 2005, Morton et al. 2002, Gagliano et al. 2003a and others). Figure 9 shows dates of surface movement of faults in southeastern Louisiana, as determined from aerial images and maps. For example, there is evidence of surface displacement along a fault segment at Bayou Long, near Lake Petit, during the photographic interval of 1976 – 1982 (Gagliano et al. 2003a). Modern fault events occur along fault segments from 1 to 5 miles in length with vertical displacement of a few inches to 5 feet or more. Lake Lery is a fault depression that is depicted on the earliest historic maps of the region. Based on analysis of historic maps, the lake had formed by 1803 (Gagliano et al. 2003a). A fault event may result in the formation of lakes and bays, submergence or breaking-up of marsh, the submergence of natural levee ridges, and the submergence and breakup of barrier islands.

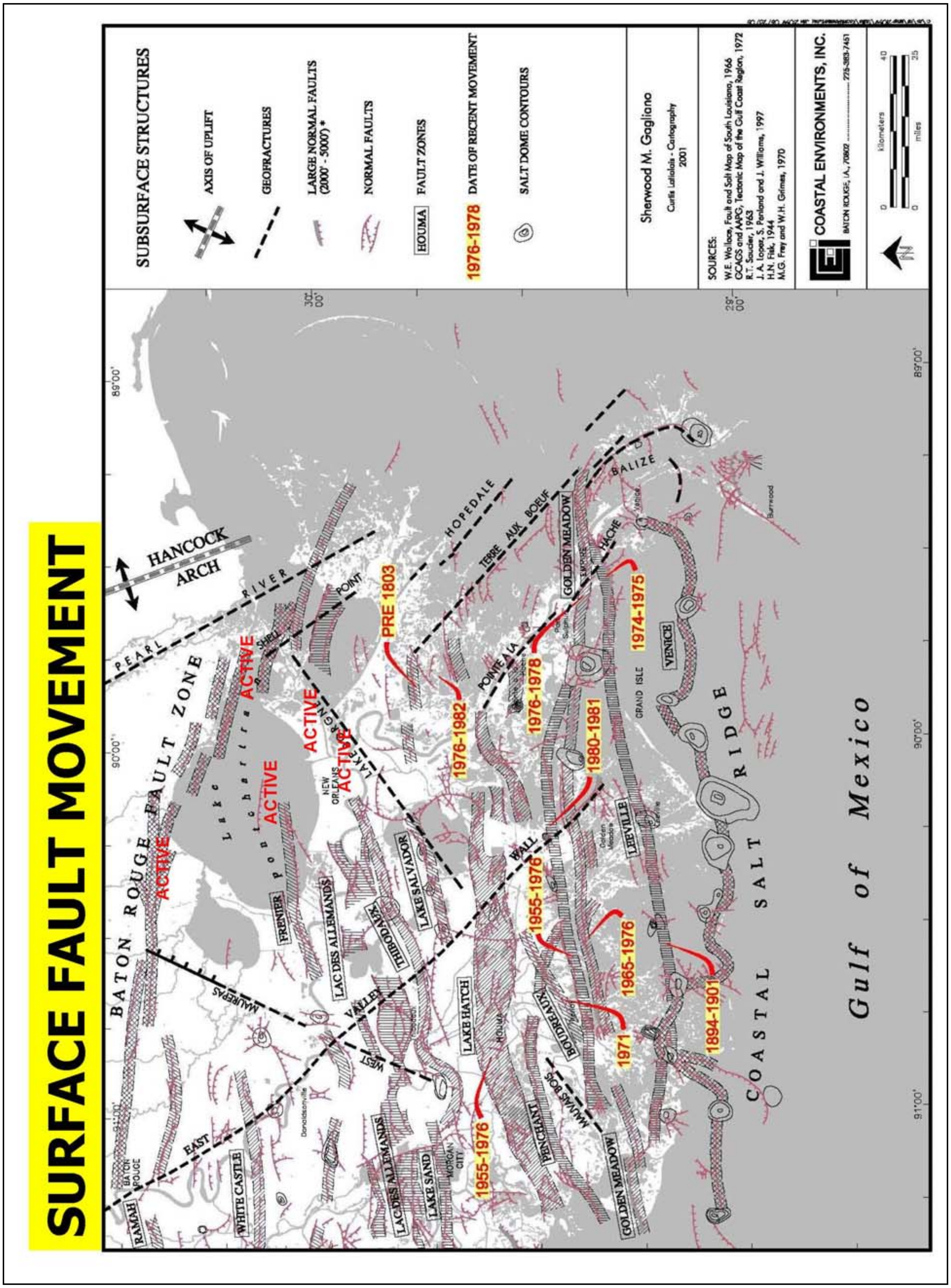

Figure 9. Map showing dates of surface fault movement in reference to known subsurface faults.

Fault movement and earthquakes

Earthquake occurrences provide insight into the location of active faults. Two categories of earthquakes have been reported in south Louisiana. The first is caused by random slippage on subsurface faults. Figure 10 shows the locations of this type of earthquake. Those within and near the GNO region occurred along the Lake Sand/Thibodaux Fault Zone. On November 6, 1958 an Intensity IV earthquake occurred within a five-to seven mile radius of downtown New Orleans. The felt area extended from Lake Pontchartrain on the north to Gretna on the south and from Harahan on the west to Arabi on the east. The earthquake was recorded on the Loyola University seismograph located in New Orleans as a 15 second vibration. The earthquake caused windows to shake and doors to rattle (Brasseaux and Lock 1992:319).

The second type of earthquake occurs when shock waves from distant earthquakes trigger slippage along local faults, which in turn may cause a secondary earthquake (Gagliano 2005)(Figure 11). An event particularly relevant to the Hurricane Katrina IHNC floodwall breach occurred on March 27, 1964 at 10:00 PM when "…swells were reported in the Industrial Canal (IHNC) NEAR new Orleans…" *UPI, New Orleans,* 1964. "'It caused our docks and vessels moored in the yards to go crazy-like, bobbing up and down, moving sideways, back and forth.' Said Leon Poche 47, superintendent of Avondale Shipyards." *AP, New Orleans* 1964a. "'The water rose about six feet above normal all at once,' said O.C. Boxton, night watchman at New Orleans Industrial Canal. 'It was one of the wildest scenes that I've seen in a long time,' he said. The water was rolling, barges began to move in and out and the lines (holding the barges) began to turn and break." *AP, New Orleans*, 1964b. "One marine company at New Orleans said the waves in the Intracoastal Canal were 'at least four or five feet." Several boats were torn loose, including a line holding an 83-foot Coast Guard vessel." *AP, New Orleans*, 1964.

This Industrial Canal event was apparently triggered by arrival of shallow shock waves from the Alaskan Earthquake of Prince William Sound of the same date and time. The intensive water disturbance indicate the presence of an active fault. The water

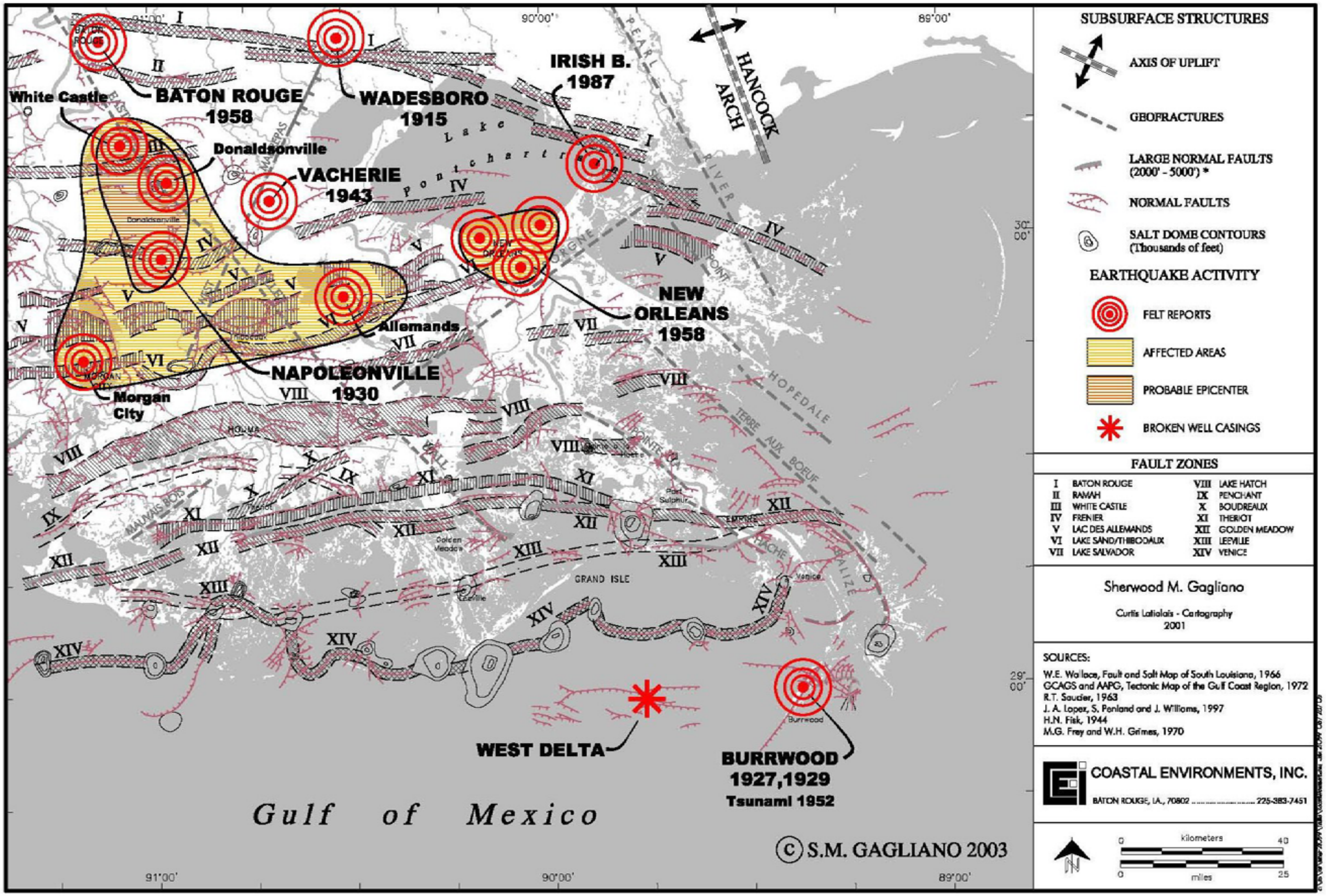

Figure 10. Locations of reported felt effects of historic earthquakes in southeastern Louisiana and correlation with known subsurface faults.

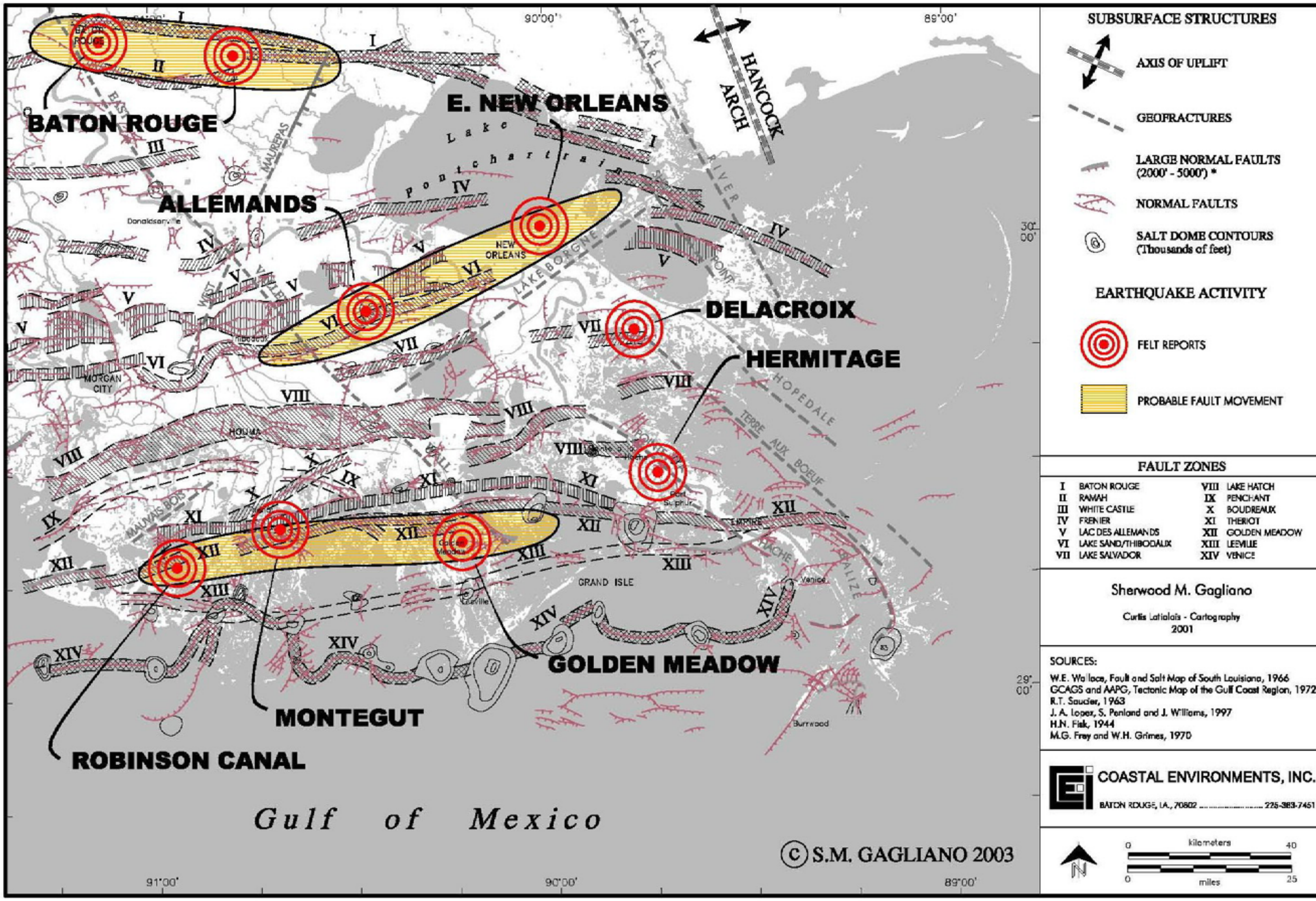

Figure 11. **Locations of reported effects of apparent secondary earthquakes in southeastern Louisiana triggered by shock waves of the M 9.2 Prince William Sound Earthquake of March 27, 1964.**

disturbances occurred in the immediate vicinity of the 2005 Hurricane Katrina floodwall breach along the east bank of the IHNC. It was this breach that caused extensive flooding in the Lower 9th Ward of New Orleans and adjacent areas of Arabi and Chalmette in St. Bernard Parish.

When accompanied by earthquakes, fault movement effects may include liquefaction, breakup of floating marsh mats and other damage to landforms and human-made structures.

Measuring movement

Rates, magnitude and frequency of movement have been determined for some faults. Several data sets have been used to measure vertical movement of land surfaces in south Louisiana, including tide gauge records, differential elevations of re-surveyed bench marks, movement of historic and archaeological features and structures, land loss, habitat change and radiometric dating of buried deposits. These measurements have been related to known faults. Tide gauge records indicate that the Little Woods area along the Lake Pontchartrain shore in New Orleans, in the general vicinity of the London Avenue Canal Breach, has one of the highest rates of subsidence in the state. Records from the tide gauge at Little Woods show a total relative sea level rise (subsidence plus eustatic rise) of 1.84 feet for the period between 1940 and 1976, for a rate of 0.51 feet per year. Further, the record is distinctly stepped, suggesting episodic fault movement.

Resurveyed bench marks at NASA - Michoud located in the general vicinity of the IHNC breach likewise show exceptionally high subsidence rates. The NASA-Michoud measurements also indicate accelerated movement during recent decades.

Recently, the National Geodetic Survey (NGS) in conjunction with the Spatial Data Center at Louisiana State University (LSU) has been re-evaluating vertical change data from benchmarks. Dr. Roy Dokka, director of the LSU team, reports that "…loss of elevation ranges from 0.3 to 0.13 feet per year across south Louisiana…" (NOAA

Magazine 2003). The NGS-LSU findings are generally consistent with those presented herein.

Types of Fault Impacts

There are three categories of fault impacts. The first is subsidence and tilting of the surface near and between faults. This effect is most pronounced on the downthrown block in the immediate vicinity of the fault. On a larger scale, entire fault-bound blocks tilt and subside. Large areas become inundated creating lakes and bays within short intervals of time. These processes are the primary cause of land loss in southeastern Louisiana.

The second category of impact is instability along the fault plane or zone. If the fault is active, movement may be slow and imperceptible, but fluids and gas may migrate toward the surface along the fault plane. Some fault planes are pencil line thin with surfaces that exhibit slickensides (smoothed and striated surfaces that result from friction along fault planes) and/or clay and mineral films. Other faults exhibit multiple, parallel planes. Still others are characterized by brecciated zones, where clay particles are broken into pellets as a result of movement along the fault zone, or sand and silt dikes that may be many feet wide. In all cases, the fault plane or fault plane zone is a deep crack in the earth's surface. Foundation conditions within the crack are poor and if a levee is built across the fault, the fault plane may become a conduit for piping or seepage under the levee. Since the faults are deep-seated, the depth of the cracks may be greater than the bottom of the longest sheet piles.

The third category of instability relates to minor earthquakes and related phenomena such as liquefaction, which as previously discussed, may result from sudden release of pent-up stress or may be triggered by shock waves from remote earthquakes. Hurricane waves are known to cause slumping along the unstable delta front area offshore from the active outlets of the Mississippi River. Could not the weight of the elevated water column in the canals combined with the pounding of wind-generated waves cause release of pent-up stress on active faults?

Relationship Between Fault and Floodwall Breaches in the GNO Area

Available data suggests that the breaches along the 17th Street Canal, the London Avenue Canal (2 breaches) and the IHNC (2 breaches) were at least partially caused by underlying faults. The 17th Street Canal and London Avenue breaches are probably on the same fault zone. The IHNC breaches may be related to the Lake Borgne Fault Zone. Breaches along the MRGO levee at the Bayou Bienvenu and Bayou Dupre floodgates are most likely the result of levee overtopping and return surge flow.

Surface inspection of the larger IHNC breach site revealed evidence of a possible fault (Figure 12). The site was inspected after a long drought. Aligned desiccation cracks and water seeps called attention to what appears to be a silt dike. As shown in the photographs in Figure 12, the feature runs under the emergency levee that was constructed to close the breach and apparently under the base of the failed floodwall. Could this silt dike have formed as a result of liquefaction during the 1964 earthquake event? While the evidence is not conclusive, it is suggestive and demands further investigation.

Fault Hazards Along Existing And Proposed Levee Alignments

Breaches in the levees along the Mississippi River in Plaquemines Parish below New Orleans may have been caused by underlying faults. The levees are constructed across several major fault zone including the large and active Lake Hatch and Golden Meadow fault zones. In some of these fault crossings, steel sheet pilings had been used to reinforce the earth levees because of foundation problems.

Breaches in levees have also occurred during two hurricanes where levees were constructed across known faults in the vicinity of Montegut, Louisiana south of Houma. As shown in the photograph in Figure 13, a flood levee was constructed across the Montegut Fault. Surface expression of this fault is distinguished by a marsh-water break. Field studies at this location showed 3.3 feet of change in elevation from the marsh surface to the pond bottom and a comparable amount of displacement of near-surface beds as determined from borings.

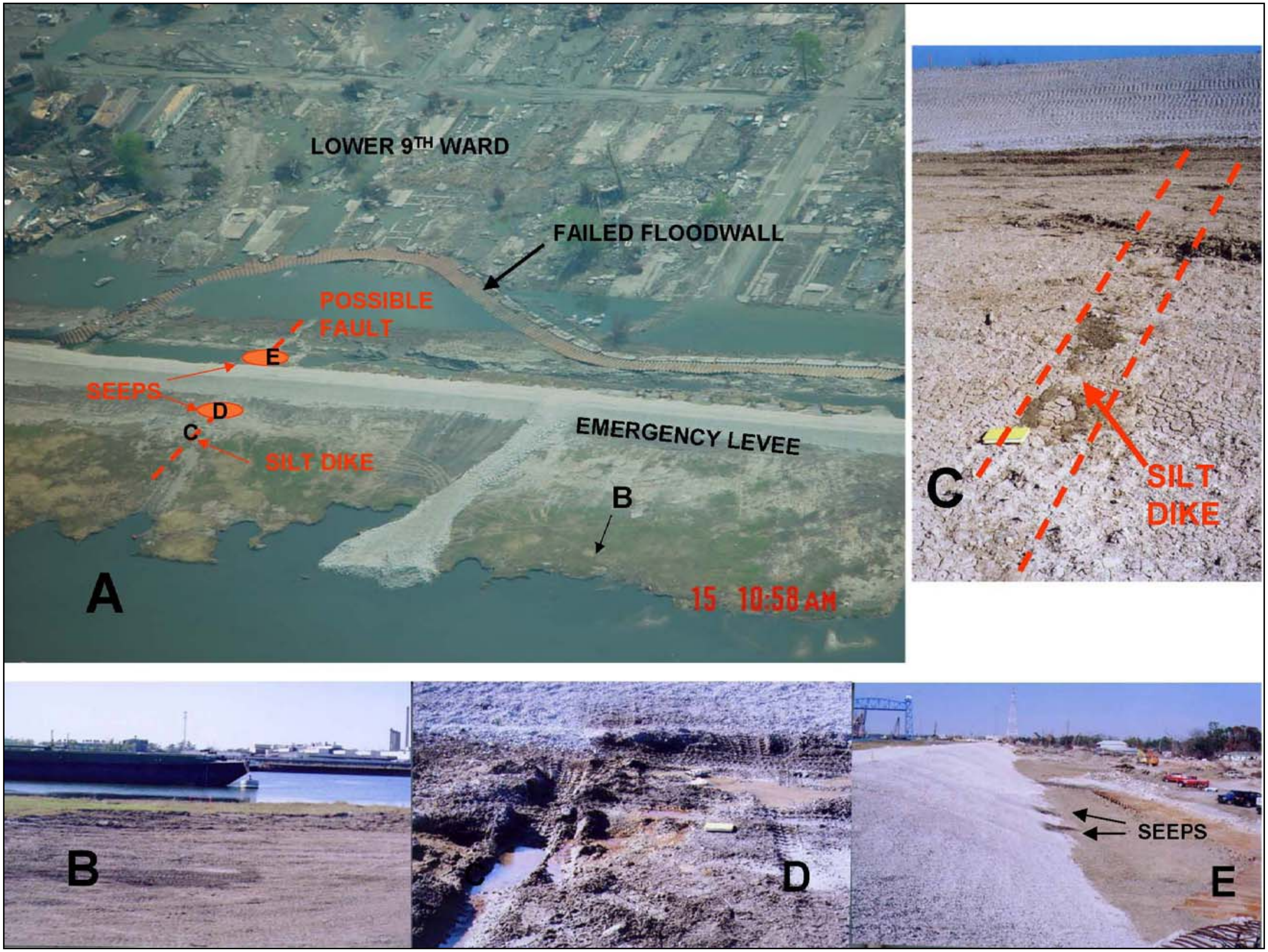

Figure 12. Floodwall breach on the east side of the Inner Harbor Navigation Canal in New Orleans. A. View looking southeast across area of floodwall failure. Uprooted steel sheet piles capped with concrete are clearly visible. B. View of canal batture looking west. Water level in the canal is approximately 1 to 1.5 feet below batture land level. Except where disturbed by vehicle movement, the batture in this area is grass-covered and not deeply scoured by water flow. C. Water seepage along possible silt dike. D. Seepage in possible silt dike at base of emergency levee, canal side. E. Seepage at base of emergency levee, east side. These seepage patches align with the possible silt dike on the west side of the levee.

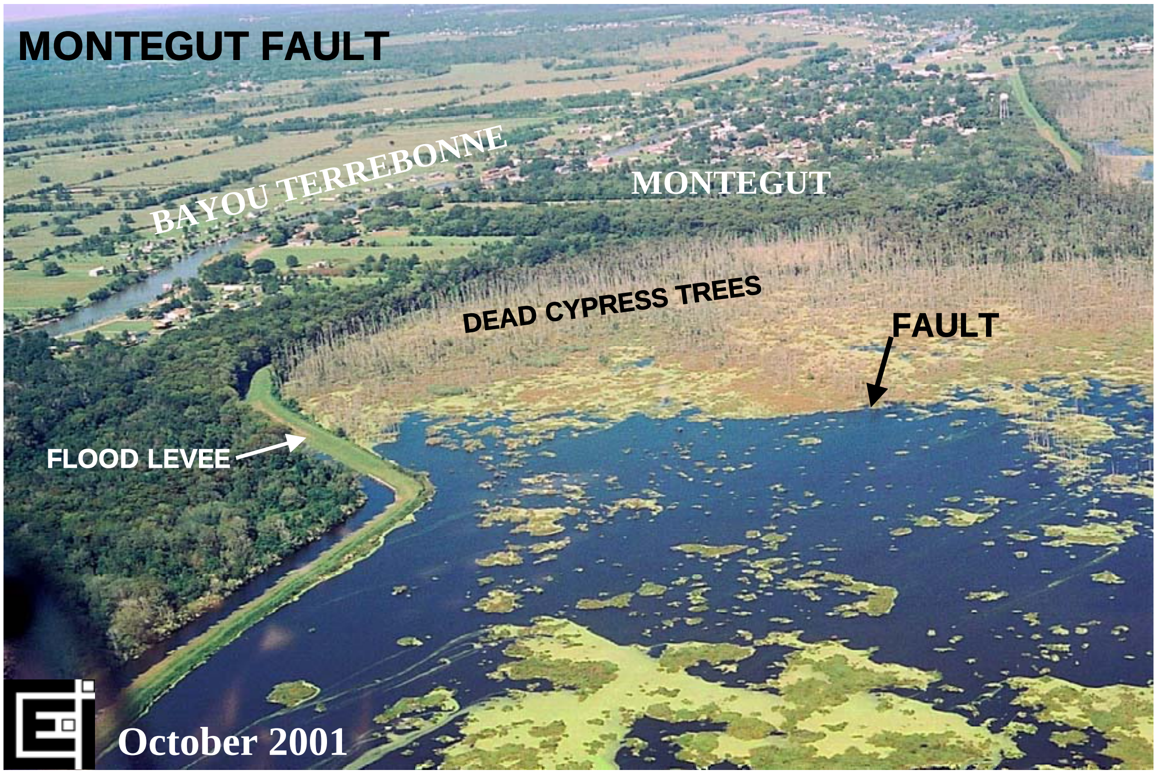

Figure 13. Flood levee constructed across an active fault at Montegut, Louisiana. The levee failed at this location during Hurricanes Isadore and Katrina. The view is looking north across a large pond and broken marsh on the down-dropped block of the fault. Note the dead cypress trees on the up-thrown block. The flood protection/drainage levee is located along the back-slope of the Bayou Terrebonne natural levee ridge. The Montegut community is located on the natural levee. Photography S.M. Gagliano, October 17, 2001.

As shown in Figure 1, proposed levee alignments in southeastern Louisiana cross major known faults at a number of locations.

Summary and Conclusions

Evidence from a number of different data sets indicates that faults in the GNO area and throughout southeastern Louisiana have been active during recent decades. Trends of known subsurface faults are parallel to lines projected between the levee breaches along the London Avenue and Seventeenth Street canals. Converging lines of evidence that suggest that the floodwall breach at the IHNC was fault-related. There are numerous other problem areas where existing and proposed levee alignments cross known, active faults.

Hurricane protection and wetland restoration have been regarded as a battle against the erosive forces of the sea, a horizontal engagement. Findings of the tectonic studies also indicate that the dominant processes are geological and the changes are vertical, thus requiring a fundamental shift in battle strategy.

While faults represent serious geological hazards in southeastern Louisiana, they do not present an insurmountable obstacle in our quest for adequate storm and flood protection. However, <u>fault hazards must be taken into consideration in planning and design of protection levees and all other infrastructure (including floodgates), as well as in the coastal restoration program</u>. To date, fault hazards have been largely ignored by the coastal engineering and planning community (Figure 14). This is partially due to the fact that fault effects and processes have only recently been understood. This is new science and it takes time to be absorbed. Another problem is that the hypothesis that fault driven subsidence is the major cause of land loss and coastal deterioration has not been politically correct. It is a natural process and there is no institutional or corporate villain.

It is difficult for public officials to tell citizens that their property is on the wrong side of a fault, and therefore, may be impossible to maintain. If our efforts to protect the Louisiana coast are to succeed, we must test each hypothesis and not arbitrarily reject those that predict outcomes that are difficult to resolve. This testimony deals with a controversial and sensitive topic and is advanced in the hope of stimulating solutions and not to stifle a program of protection and restoration of coastal Louisiana.

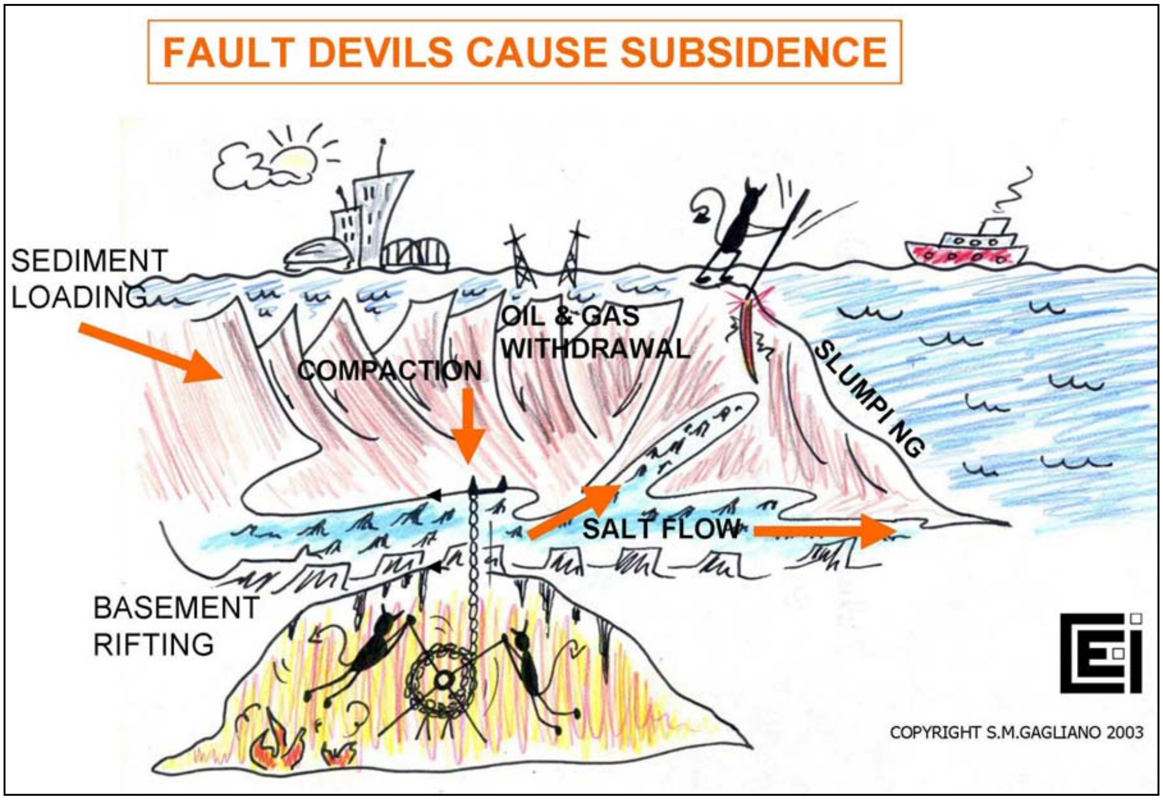

Figure 14. Fault induced subsidence is not a politically correct theory.

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